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INCREASING GROWTH AND YIELD OF YOUNG SPRUCE PULPWOOD STANDS BY GIRDLING HARDWOODS

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INTRODUCTION

Any means of increasing the representation and growth rate of red spruce in the mixed spruce-hardwood forests of the Northeast has particular importance for foresters and pulpwood operators of the region. In this so-called spruce region only a small percentage of the forest actually consists of pure stands of conifers—red spruce (*Picea rubra* Link) and balsam fir (*Abies balsamea* (L.) Miller)—by far the greater part of the area being occupied by a mixture of these species with northern hardwoods.

Most of the spruce pulpwood consumed by the mills of the region comes from stands in which various hardwood species constitute from 25 to 75 percent of the volume. In many localities no market exists or is in view for the hardwoods. In cutting operations in these forests it is the common practice to remove the spruce and balsam fir only, which leaves standing large numbers of hardwoods of all sizes. Much of this hardwood timber is defective and of poor form, particularly on areas that have been cut over repeatedly for coniferous pulpwood species. On such areas defect which might normally occur elsewhere is increased by rot-producing fungi gaining entrance through logging injuries. The hardwood overstory not only retards the growth of spruce and fir of merchantable size, but prevents young trees of these species from developing to merchantable size at a satisfactory rate (fig. 1). Thus the area of coniferous pulpwood-producing land is being continually reduced.

A similar situation develops in young spruce-hardwood stands which have sprung up following clear cutting, fire, or blow-down. The competition from overtopping hardwoods may be even more serious in these young stands, because they are generally more dense and will handicap the softwoods for a longer period than would decadent residual hardwoods.

[1] Maintained by the U. S. Department of Agriculture at New Haven, Conn., in cooperation with Yale University.

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Since the fall of 1905 the United States Forest Service has had in progress at Corbin Park, in central New Hampshire, an experiment in girdling overtopping hardwoods in a mixed spruce-hardwood stand. The experiment has had two purposes: (1) To determine the feasibility of converting a mixed spruce-hardwood stand into a pure stand of conifers through girdling the hardwoods; and (2) to determine the effect of selective girdling on the growth, quality, and soundness of the remaining timber. The plots have been remeasured at regular intervals. Sufficient time has now elapsed to show definitely what results may be expected from the different degrees of liberation by girdling effected in the experiment.

The results reported in this circular are the first of their kind based on actual long-time records.

REVIEW OF LITERATURE

Brewster and Larsen (*2*),[2] experimenting with different methods of ridding a stand of undesirable species, concluded that girdling with

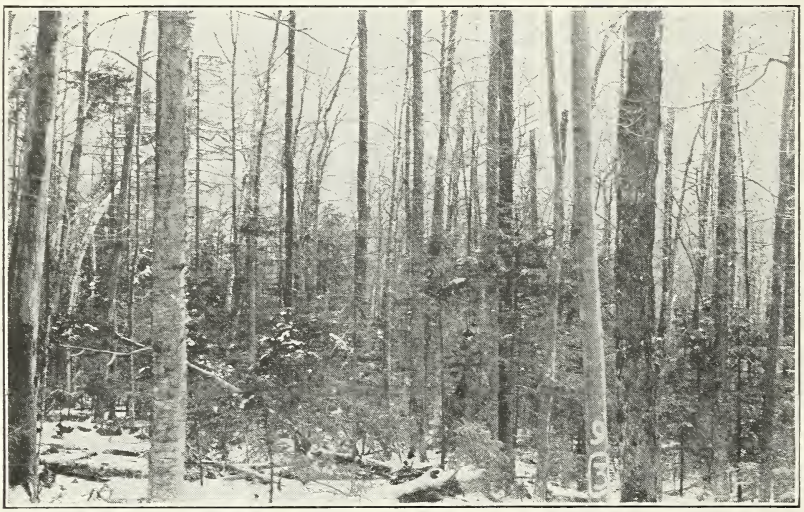

FIGURE 1.—Young spruce stand overtopped by hardwoods. (Ungirdled plot 3, 1936.)

an ax notch is probably the most desirable method in respect to both cost and effectiveness.

Cary (*4*), a pioneer in the field of girdling, showed that marked increase in both diameter and height growth occurred in trees released by girdling in an experimental tract in northern Maine. These findings are in harmony with those of Churchill (*5*), who girdled a tract of several thousand acres on the Finch, Pruyn & Co. holdings in the Adirondacks.

Robertson (*7*) attributes to the effects of girdling an average annual increase in spruce and fir over normal of 8.2 cubic feet per acre during a 6-year period on an experimental girdling plot in Quebec. In a similar experiment, also in Quebec, Best (*1*) found increased increment due to girdling to average 15.7 cubic feet annually over a 6-year period. Studies conducted by Plice and Hedden (*6*) on girdled tracts reported on by Churchill (*5*) showed that 5 years after girdling

[2] Italic numbers in parentheses refer to Literature Cited, p. 18.

released spruce were growing 25.1 percent more rapidly in basal area than unreleased spruce, and released balsam fir 99.6 percent faster than unreleased balsam fir.

The New England section of the Society of American Foresters (*3, 8*) and the writer (*9, 10*) present data to show that from a financial standpoint girdling of hardwoods to release spruce is a profitable undertaking.

THE EXPERIMENTAL PLOTS

DESCRIPTION

The experimental area at Corbin Park, N. H., lies some 200 to 300 feet below a main ridge, on a gently sloping bench with a general easterly exposure, approximately 1,700 feet above sea level. The soil is of excellent quality, consisting of a deep, well-drained sandy loam overlain by 2 to 3 inches of well-decomposed humus and hardwood litter. The stand consisted of an overstory made up almost entirely of northern hardwoods and an understory of spruce and other conifers, mostly in the reproduction stage, a condition prevailing over considerable areas in the second-growth spruce-hardwood forests of the Northeast. Conditions were similar in many respects also to those prevailing over extensive areas in the mixed forests from which only merchantable-sized spruce had been removed, except that in general the hardwoods on the plots were younger.

Three half-acre plots were established on this area in the fall of 1905 and were numbered 1, 2, and 3. The stands on the plots varied but little with respect to species, composition, age, total basal area, density, thrift, or reproduction. Nearly all the trees more than 2 inches in diameter were hardwoods (table 1). On plots 2 and 3, largetooth aspen (*Populus grandidentata* Michx.) was the most abundant species, followed, in the order named, by one of the birches [paper birch (*Betula papyrifera* Marsh) or yellow birch (*B. lutea* Michx.)], sugar maple (*Acer saccharum* Marsh), red spruce, and beech (*Fagus grandifolia* Ehrh.). On plot 1 yellow birch predominated.

TABLE 1.—*Number of trees per acre before treatment, by species and diameter class* [1]

Species and diameter class (inches)	Trees on plot 1	Trees on plot 2	Trees on plot 3
Beech:	*Number*	*Number*	*Number*
2–4	26	24	12
5–9	2		
All sizes	28	24	12
Yellow birch:			
2–4	178	80	94
5–9	58	16	16
All sizes	236	96	110
Paper birch:			
2–4	52	66	42
5–9	72	78	52
10–14	8		
All sizes	132	144	94
Sugar maple:			
2–4	78	78	[2] 16
5–9	22	14	12
All sizes	100	92	28
Aspen:			
2–4	20	26	32
5–9	74	176	188
10–14	40	36	26
All sizes	134	238	246
White ash:			
2–4	10		
5–9	34	2	
All sizes	44	2	
All hardwoods:			
2–4	364	274	196
5–9	262	286	268
10–14	48	36	26
All sizes	674	596	490
Red spruce:			
2–4	78	54	22
5–9	2		2
All sizes	80	54	24

[1] All diameter measurements taken outside the bark at breast height (4.5 feet above ground level).
[2] Includes 1 red maple.

Although the stand was relatively even-aged, the aspen averaged considerably larger than the other species. Most of the aspen was more than 6 inches in diameter; with the exception of paper birch, very few trees of other species were more than 4 inches in diameter.

At the time of plot establishment the hardwood stands on plots 1 and 2 were practically uniform, their basal areas amounting to 109.71 and 112.40 square feet per acre, respectively. On plot 3 the hardwood stand was somewhat less dense, its basal area totaling 96.76 square feet.

On all the plots the hardwood crowns formed an extremely dense canopy, the area of which was in no case less than twice the land area (table 2). This high ratio of crown area to land area was due to the wide range of shade tolerance represented by the species composing the stand.

TABLE 2.—*Crown area per acre of land area, before girdling, by species*

Plot no.	Beech	Yellow birch	Paper birch	Sugar maple	Aspen	White ash	Red spruce	Total
	Acres	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*
1	0.040	0.460	0.538	0.208	0.900	0.184	0.014	2.344
2	.022	.192	.508	.188	1.414	.006	.056	2.386
3	.020	.212	.342	[1].102	1.458	-------	.044	2.178

[1] Includes 0.002 acre of red maple.

The notes recorded at the time of plot establishment indicate that there was present at that time a uniformly excellent stand of coniferous reproduction ranging in size from seedlings to saplings 3 inches in diameter. A count of the reproduction present in 1905 on plot 3 (table 3) showed that more than four-fifths of the reproduction was coniferous and that this was almost pure spruce. It showed also that sugar maple constituted more than half the hardwood reproduction, with yellow birch next in order. No detailed reproduction tallies were made on plots 1 and 2 in 1905; but descriptive notes recorded then support the assumption that the stands on these plots closely resembled that on plot 3 except that the representation of spruce 2.6 inches or more in diameter was appreciably greater, both in number of trees and in basal area.

TABLE 3.—*Number of seedlings and saplings per acre on plot 3 in 1905, by size and species*

Size class	Conifers			Commercial hardwood species					
	Red spruce	Balsam fir	Total	Sugar maple	Yellow birch	Paper birch	White ash	Beech	Total
	Number	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
0 to 2 feet in height	460	18	478	26	-------	-------	4	14	44
2.1 to 4 feet in height	580	2	582	-------	-------	-------	-------	2	2
4.1 to 6 feet in height	428	-------	428	8	2	-------	-------	-------	10
6.1 feet in height to 1.5 inches d. b. h.[1]	316	-------	316	128	66	-------	-------	2	196
1.6 to 2.5 inches d. b. h.[1]	128	-------	128	80	92	2	-------	10	184
Total	1,912	20	1,932	242	160	2	4	28	436
			Percent						*Percent*
Percentage of total reproduction stand	-------	-------	81.6	-------	-------	-------	-------	-------	18.4

[1] Diameter breast high (4.5 feet above ground level).

TREATMENT

The plan for treatment of plots was as follows: On plot 1, 50 percent of the hardwoods were to be girdled; on plot 2 practically all the hardwoods were to be girdled; and plot 3 was to be held intact as a control.

The first girdling operation [3] took place in the winter following plot establishment in 1905. The extent to which it reduced the basal area of the various hardwood species on the two plots is shown in table 4. On plot 1 the original hardwood basal area per acre was reduced by approximately 36 percent. About 77 percent of the reduction was in aspen. On plot 2 the hardwood basal area per acre was reduced by 52 percent. Here 88 percent of the basal area eliminated by girdling was of aspen.

TABLE 4.—*Basal area per acre, by species, of all trees 2.6 inches or more in breast-height diameter as affected by girdling of hardwoods*

When observed and plot no.	Beech	Yellow birch	Paper birch	Sugar maple	Aspen	White ash	Total hardwoods	Red spruce	Total
Before treatment, 1905:	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*
1	1.59	18.62	25.43	8.32	46.18	9.57	109.71	3.25	112.96
2	1.07	8.68	23.50	[1] 7.25	71.62	.28	112.40	2.13	114.53
3	.70	8.08	14.72	3.98	69.28	----	96.76	1.40	98.16
After treatment, 1905:									
1	.98	14.42	23.44	6.76	15.52	8.94	70.06	3.25	73.31
2	1.07	8.68	16.68	7.25	19.84	.28	53.80	2.13	55.93
3	.70	8.08	14.72	[1] 3.98	69.28	----	96.76	1.40	98.16
After treatment, 1915:									
1	----	9.97	12.21	2.60	.23	8.64	33.65	5.55	39.20
2	.62	2.29	.96	.14	----	----	4.01	9.59	13.60
3	1.00	12.18	21.48	[2] 6.10	59.44	----	100.20	3.81	104.01
1935:									
1	.11	14.94	20.10	[3] 7.39	----	15.47	58.01	59.73	117.74
2	.81	8.01	3.44	[4] 5.71	1.21	.08	19.26	98.30	117.56
3	2.44	28.50	24.09	[5] 17.45	22.35	----	94.83	9.12	103.95

[1] Includes 0.10 square foot of red maple.
[2] Includes 0.20 square foot of red maple.
[3] Includes 0.78 square foot of red maple.
[4] Includes 0.20 square foot of striped maple.
[5] Includes 0.53 square foot of red maple.

The second girdling took place in 1915. On plot 1 (fig. 2) it approached in severity the 1905 girdling on plot 2. The 70.06 square feet of hardwood basal area per acre left on plot 1 in 1905 had increased by 1915 to 88.81 square feet. The second girdling reduced it 62 percent. Approximately half the reduction was in aspen and birch. On plot 2 the 1915 operation was very severe, reducing the hardwood basal area per acre from 60.34 square feet to 4.01 square feet.

Table 5 shows the number and percentage of hardwoods eliminated through girdling in 1905 and in 1915, by size classes. The 1905 girdling was heavier in the large diameter classes than in the 2- to 4-inch diameter class. The 1915 girdling was decidedly heavier than that of 1905 in all diameter classes on both plots with the exception of the 10- to 14-inch class on plot 1. Although after the first girdling, plot 1 still had more hardwoods than the check plot and plot 2 had almost as many, competition was actually much less owing to heavy girdling in the larger size classes (table 6).

[3] Some of the trees eliminated from the stand were felled. For the sake of convenience, these felled trees were included in the numbers recorded as girdled.

The girdling operations in 1915 reduced the hardwood crown area on plot 1 by more than 60 percent, and reduced that on plot 2 by

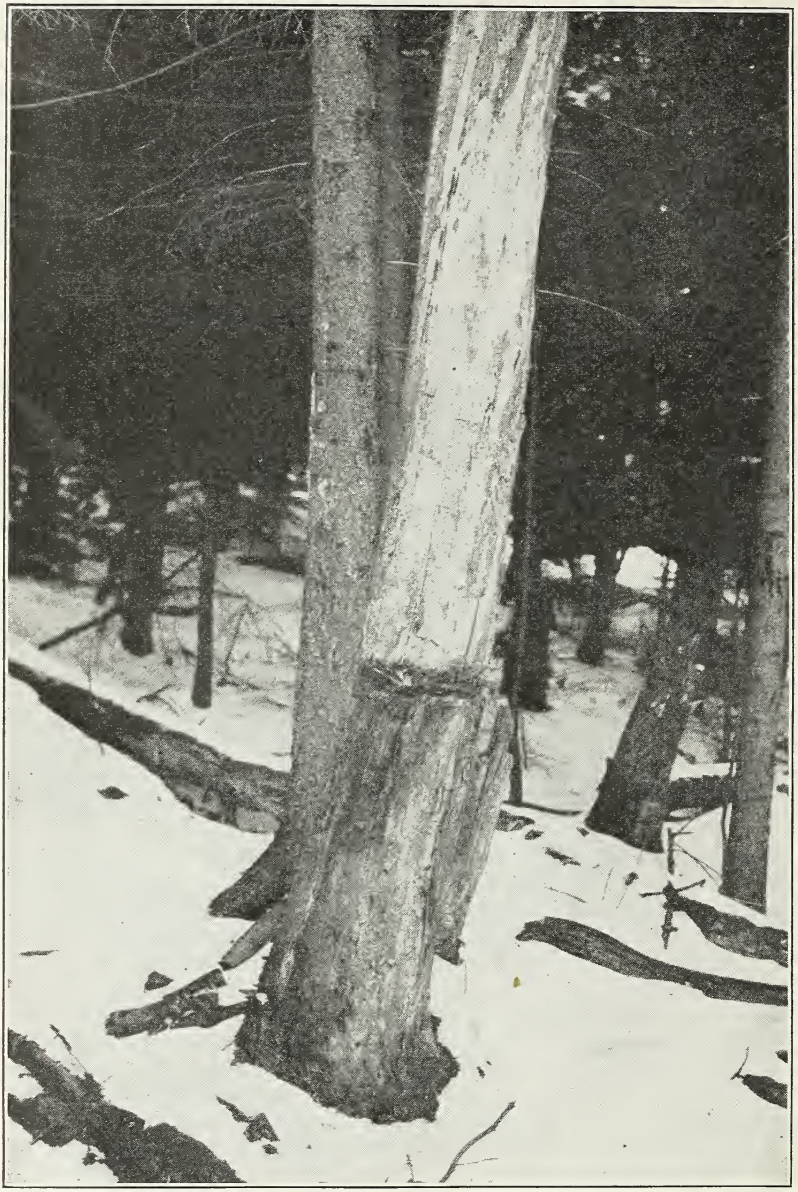

FIGURE 2.—This 10-inch yellow birch on plot 1, girdled in 1915, was one of the few girdled hardwoods still standing in 1936.

nearly 85 percent, liberating practically all spruce saplings and trees on plot 2, but leaving 20 percent of those on plot 1 still overtopped by hardwoods.

TABLE 5.—*Hardwoods per acre girdled in 1905 and in 1915, by diameter classes*

Year and diameter class (inches)	Plot 1			Plot 2			Plot 3—all trees
	All trees	Girdled trees		All trees	Girdled trees		
1905:	*Number*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*
2–4	364	82	22.5	274	8	2.9	196
5–9	262	42	16.0	286	118	41.3	268
10–14	48	40	83.3	36	32	88.9	26
All sizes	674	164	24.3	596	158	26.5	490
1915:							
2–4	162	136	84.0	134	120	89.6	240
5–9	238	152	63.9	198	178	89.9	208
10–14	26	16	61.5	20	20	100.0	52
All sizes	426	304	71.4	352	318	90.3	500

EFFECTS OF GIRDLING HARDWOODS

ON STAND COMPOSITION

At the time of their establishment, the minimum hardwood component in the plots was 89.4 percent by number of trees and 97.1 percent by basal area (tables 6 and 7). Girdling on plots 1 and 2 radically changed the relative proportions of hardwoods and conifers. By 1935 the representation of red spruce in number of trees had risen from 10.6 percent to 82.3 percent on plot 1, and from 8.3 percent to 89.9 percent on plot 2. In basal area, the proportion of spruce had risen to 50.7 percent on plot 1 and to 83.6 percent on plot 2. On the check plot, where composition had been affected by natural forces only, the proportion of spruce in number and basal area had increased steadily but very slowly.

TABLE 6.—*Red spruce and hardwood trees 2.6 inches or more diameter breast high per acre in 1905 and at intervals thereafter*

When observed	Plot 1					Plot 2					Plot 3				
	Hardwoods		Red spruce		Total	Hardwoods		Red spruce		Total	Hardwoods		Red spruce		Total
	Number	*Percent*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Number*	*Percent*	*Number*	*Percent*	*Number*
1905:															
Before girdling	674	89.4	80	10.6	754	596	91.7	54	8.3	650	490	95.3	24	4.7	514
After girdling	510	86.4	80	13.6	590	438	89.0	54	11.0	492	490	95.3	24	4.7	514
1910	468	86.0	76	14.0	544	386	87.7	54	12.3	440	438	96.0	18	4.0	456
1915:															
Before girdling	426	79.5	110	20.5	536	352	66.9	174	33.1	526	378	84.8	68	15.2	446
After girdling	122	52.6	110	47.4	232	34	16.3	174	83.7	208	378	84.8	68	15.2	446
1920	116	56.3	90	43.7	206	40	18.5	176	81.5	216	392	84.8	70	15.2	462
1925	100	56.2	78	43.8	178	32	15.5	174	84.5	206	322	83.0	66	17.0	388
1930	140	19.7	570	80.3	710	92	10.8	760	89.2	852	408	76.1	128	23.9	536
1935	138	17.7	642	82.3	780	94	10.1	840	89.9	934	438	78.5	120	21.5	558

TABLE 7.—*Basal areas of red spruce and hardwood trees 2.6 inches or more diameter breast high per acre in 1905 and at intervals thereafter*

When observed	Plot 1					Plot 2					Plot 3				
	Hardwoods		Red spruce		Total	Hardwoods		Red spruce		Total	Hardwoods		Red spruce		Total
	Square feet	*Percent*	*Square feet*	*Percent*	*Square feet*	*Square feet*	*Percent*	*Square feet*	*Percent*	*Square feet*	*Square feet*	*Percent*	*Square feet*	*Percent*	*Square feet*
1905:															
Before girdling	109.71	97.1	3.25	2.9	112.96	112.40	98.1	2.13	1.9	114.53	96.76	98.6	1.40	1.4	98.16
After girdling	70.06	95.6	3.25	4.4	73.31	53.80	96.2	2.13	3.8	55.93	96.76	98.6	1.40	1.4	98.16
1910	81.04	95.4	3.88	4.6	84.92	56.19	94.7	3.14	5.3	59.33	100.76	98.8	1.26	1.2	102.02
1915:															
Before girdling	88.81	94.1	5.55	5.9	94.36	60.34	86.3	9.59	13.7	69.93	100.20	96.3	3.81	3.7	104.01
After girdling	33.65	85.8	5.55	14.2	39.20	4.01	29.5	9.59	70.5	13.60	100.20	96.3	3.81	3.7	104.01
1920	38.89	86.6	6.00	13.4	44.89	4.72	25.1	14.08	74.9	18.80	104.03	95.8	4.55	4.2	108.58
1925	41.69	86.0	6.78	14.0	48.47	7.45	27.2	19.91	72.8	27.36	96.45	95.1	4.92	4.9	101.37
1930	51.81	54.0	44.09	46.0	95.90	16.89	19.0	71.99	81.0	88.88	115.37	93.2	8.48	6.8	123.85
1935	58.01	49.3	59.73	50.7	117.74	19.26	16.4	98.30	83.6	117.56	94.83	91.2	9.12	8.8	103.95

DEVELOPMENT OF SPRUCE REPRODUCTION

The development of spruce reproduction following the girdling is indicated in table 8. In 1910 the plots showed a very uniform stocking, with spruce seedlings averaging about 1,000 and spruce saplings 719 per acre. That removal of a portion of the hardwood canopy in 1905 and again in 1915 hastened the development of the taller spruce reproduction into tree size classes is indicated by the subsequent representation of these classes on plots 1 and 2 as compared with plot 3.

TABLE 8.—*Number of spruce seedlings, saplings, and trees per acre in stated years*

Plot no. and year	Seedlings [1]	Saplings [2]	Trees [3]	Total	Plot no. and year	Seedlings [1]	Saplings [2]	Trees [3]	Total
1:	*Number*	*Number*	*Number*	*Number*	3:	*Number*	*Number*	*Number*	*Number*
1905	[4]	554	80	[4]	1905	1,468	444	24	1,936
1910	1,064	840	76	1,980	1910	952	532	18	1,502
1915	876	458	110	1,444	1915	748	256	68	1,072
1920	468	928	90	1,486	1920	668	562	70	1,300
1927	510	516	474	1,500	1927	658	456	98	1,212
1930	300	452	570	1,322	1930	700	352	128	1,180
1935	450	532	642	1,624	1935	425	416	120	961
2:									
1905	[4]	569	54	[4]					
1910	1,056	784	54	1,894					
1915	666	678	174	1,518					
1920	902	842	176	1,920					
1927	455	492	638	1,585					
1930	240	386	760	1,386					
1935	40	356	840	1,236					

[1] Less than 0.6 inch diameter breast high.
[2] 0.6 inch to 2.5 inches diameter breast high.
[3] 2.6 inches or more diameter breast high.
[4] Not tallied in 1905.

RESPONSE OF HARDWOODS

On extensive areas in the mixed spruce-hardwood type the girdling of hardwoods to release conifer species would not involve destruction of any hardwood timber having a market value or likely soon to acquire such value. Limited areas in this type, however, include hardwoods having present or potential market value. This fact gives interest to the effects of selective girdling on the hardwood element in the stand.

As has been stated previously, on plot 2 practically all the hardwoods were girdled, regardless of their condition or value. On plot 1 only the slow-growing and defective hardwoods and those of least desirable species were girdled, about 28.6 percent of the hardwood trees being left standing. The "improvement girdling" on plot 1 not only accelerated the growth rate of the residual hardwoods but greatly improved the composition of the hardwood element of the stand (table 4). The basal area representation of white ash (*Fraxinus americana* L.) was increased by the light initial girdling from 8.7 percent to 12.8 percent and by the second girdling to nearly 26 percent of the total hardwood stand. The effect of this type of girdling on total hardwood production is shown in table 9. The fact that the net increase in basal area of sound hardwoods on the check plot during the first period was less than one-fifth that on plot 1 is due in large measure to the death of a considerable number of large defective aspen trees on the check plot. During the 20-year period following the 1915 girdling, the moderately girdled plot again showed the greatest net hardwood increment, on the heavily girdled plot there was less, and on the control plot there was an actual decrease.

TABLE 9.—*Basal area of hardwoods per acre, in 1905, 1915, and 1935*

Plot no.	1905		Increase, 1905 to 1915	1915		Increase or decrease, 1915 to 1935	1935	Periodic annual increase or decrease	
	Before girdling	After girdling		Before girdling	After girdling			1905 to 1915	1915 to 1935
	Sq. ft.	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
1	109.71	70.06	18.75	88.81	33.65	24.36	58.01	1.88	1.22
2	112.40	53.80	6.54	60.34	4.01	15.25	19.26	.65	.76
3	96.76	96.76	3.44	100.20	100.20	−5.38	94.82	.34	−.27

ON THE GROWTH RATE OF SPRUCE

HEIGHT GROWTH

Table 10 shows a comparison of height growth of spruce on the girdled plots and on the control plot. Data for comparative height growth are available for only an 8-year period, since tree heights were measured only in 1927, 1930, and 1935. Height measurements were taken on approximately 10 percent of all conifers 1 inch or more in breast-height diameter. Average height growth of spruce was found to vary directly with the degree of release.

TABLE 10.—*Height growth of spruce trees* [1] *on girdled plots and on check plot*

Plot no.	Trees measured		Average height			Average annual height growth, 1927–35
	1927 and 1930	1935 [2]	1927	1930	1935	
	Number	*Number*	*Feet*	*Feet*	*Feet*	*Feet*
1	24	22	21.5	23.7	26.2	0.59
2	16	12	23.3	26.8	29.6	.79
3	13	10	23.5	24.0	25.0	.19

[1] 1 inch or more diameter breast high, in 1927.
[2] Decrease in number due to mortality.

DIAMETER GROWTH

That release from overtopping hardwoods profoundly influenced the diameter growth of the spruce is clearly shown by a comparison between plots as to diameter growth of the original red spruce trees, that is, red spruces that were 2.6 inches [4] or more d. b. h. at the time of the first girdling operation (table 11). Between 1905 and 1935, on plot 1 the average breast-height diameter for this size class increased at a rate of 1 inch in 10 years, and on plot 2, on which girdling was heaviest, at a rate of 1 inch in 7.9 years. During the same period the average breast-height diameter for this size class on the control plot increased only at the rate of 1 inch in 18.8 years.

The acceleration in diameter growth of spruce following girdling of hardwoods is indicated also by the rapidity with which spruce saplings attained merchantable size, that is, a breast-height diameter of 5 inches (table 12).

[4] A few trees less than 2.6 inches in d. b. h. in 1905 were included in these measurements.

TABLE 11.—*Average diameter of original red spruce trees in 1905* [1] *and at 5-year intervals thereafter, and their periodic annual diameter increase*

Plot no.	Average diameter in—							Average annual diameter increment, 1905–35
	1905	1910	1915	1920	1925	1930	1935	
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1	2.5	2.9	3.2	3.7	4.2	5.0	5.5	0.10
2	2.7	3.3	3.9	4.5	5.2	5.9	6.5	.13
3	3.0	3.4	3.8	4.0	4.2	4.5	4.6	.05

[1] 2.6 inches or more diameter breast high, with a few exceptions.

TABLE 12.—*Number of conifer pulpwood trees of merchantable size* [1] *per acre in 1905 and at 5-year intervals thereafter*

Plot no.	1905	1910	1915	1920			1925				1930					1935					
	5 inches	5 inches	5 inches	5 inches	6 inches	Total	5 inches	6 inches	7 inches	Total	5 inches	6 inches	7 inches	8 inches	Total	5 inches	6 inches	7 inches	8 inches	9 inches	Total
	No.	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*	*No.*
1	2	----	----	2	----	2	16	----	----	16	74	14	4	----	92	108	46	16	4	----	174
2	----	----	8	14	4	18	48	16	4	68	136	46	18	4	204	178	112	38	16	4	348
3	2	2	2	4	----	4	6	----	----	6	12	----	----	----	12	18	2	----	----	----	20

[1] 5 inches or more diameter breast high.

In 1905 there were no merchantable-sized conifers on plot 2, and the representation of such trees on plots 1 and 3 totaled but two per acre. The tallies of 1910 and 1915 showed no merchantable-sized spruce on plot 1. In 1935 plot 2 had 348 such trees per acre; plot 1, 174; and plot 3, only 20.

The most rapid increase in diameter growth followed the heavier girdling, which took place in 1915. In this operation, it should be borne in mind, not only were larger numbers of hardwoods girdled but more than 80 percent of these were of dense-foliaged species such as maple, beech, and birch, whereas the girdling of 1905 involved primarily the light-foliaged aspen.

BASAL AREA

The rapid growth on the girdled plots is well illustrated by the increase in basal area of all red spruce trees (table 13). The increase was greatest on the plot heavily girdled, less on the plot moderately girdled, and least of all on the control plot.

TABLE 13.—*Basal area per acre of all red spruce 1 inch or more in diameter breast high in 1905 and at 5-year intervals thereafter*

Plot no.	1905	1910	1915	1920	1925	1930	1935	Average yearly increase
	Sq. ft.	*Sq. ft*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
1	8.99	13.68	14.86	22.00	35.20	52.01	67.26	1.94
2	8.71	14.64	22.04	32.57	51.55	78.35	103.55	3.16
3	6.11	8.68	9.67	12.19	12.85	12.93	13.43	.24

VOLUME GROWTH

The stimulating effect of release on the growth rate of spruce is brought out also through a comparison of the three plots as to average volume of the original spruce trees at 5-year intervals (table 14). Although at the beginning of the experiment the volume of the average spruce tree on the control plot was considerably greater than that on either of the two treated plots, this relation was reversed within 10 years on the plot heavily girdled and within 20 years on the plot moderately girdled. By 1935 the volume of the average original red spruce tree on plot 3 was less than 45 percent of that on plot 2 and approximately 65 percent of that on plot 1. The average yearly volume increases of the original red spruce trees on plots 1 and 2 were more than two and three times as great, respectively, as that on the control plot.

TABLE 14.—*Average volume of original red spruce trees 2.6 inches or more d. b. h. in 1905 and at 5-year intervals thereafter*

Plot no.	1905	1910	1915	1920	1925	1930	1935	Average yearly increase
	Cu. ft.	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*	*Cu. ft.*
1	0.43	0.60	0.78	1.07	1.52	2.24	2.60	0.07
2	.52	.83	1.28	1.74	2.50	3.46	3.90	.11
3	.66	.90	1.15	1.29	1.37	1.65	1.70	.03

As an index of the potential conifer pulpwood production of the stands on the plots, the total volumes of all spruce trees 1 inch or more diameter breast high are shown in table 15 and figure 3. Heavily girdled plot 2, which in 1905 had about 7 percent less spruce growing stock than plot 1, by 1910 had forged ahead, showing a volume of 160.24 cubic feet as against 147.38 cubic feet on plot 1. Between 1905 and 1935 the spruce volume on plot 2 showed an average annual increase of 50.60 cubic feet; during the same period the spruce volume on plot 1 had an average annual increase of 29.28 cubic feet, which is only 58 percent of the growth rate recorded for plot 2. On the control plot during the same period, an average annual increase of only 3.63 cubic feet was shown.

TABLE 15.—*Volume per acre of all red spruce trees 1 inch or more diameter breast high in 1905 and at 5-year intervals thereafter*

Plot no.	1905	1910	1915	1920	1925	1930	1935
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
1	95.68	147.38	163.67	252.32	387.00	712.18	974.22
2	89.15	160.24	256.50	412.26	623.50	1,138.22	1,607.24
3	62.82	94.08	107.40	141.94	154.00	160.12	171.70

Average annual volume growth on the treated plots showed a more decided gain during the later period of the experiment (table 16), owing to the fact that a larger number of stems reached tree size during that period. Whereas during the period 1905–20 the annual volume growth on plots 1 and 2 averaged 10.44 and 21.54 cubic feet, respectively, in the period 1920–35 it rose to 48.13 and 79.67 cubic feet, respectively. On the control plot exactly the reverse trend was

manifested; the average annual growth fell off decidedly after 1920, dropping from 5.27 to 1.98 cubic feet.

Merchantable spruce volumes for the plots are indicated in table 17. Comparison of these volumes with total spruce volumes, given in table 15, shows that for the first 20 years following treatment practically all of the material was of non-merchantable size. Thereafter, however, the percentage of merchantable material on the plots with

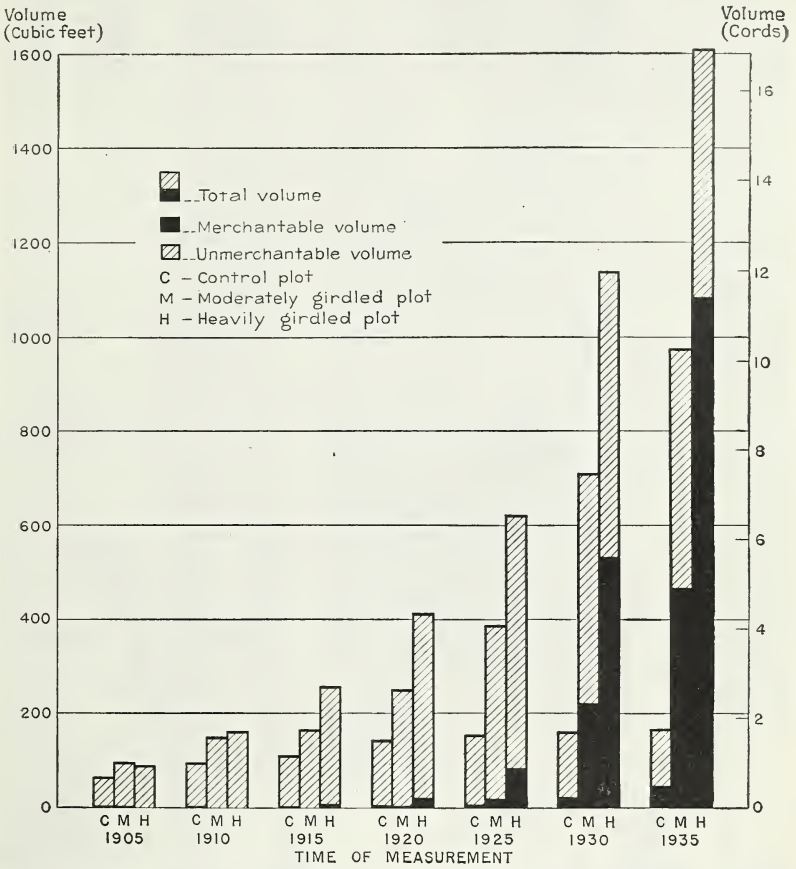

FIGURE 3.—Total and merchantable volumes in cubic feet and cords per acre of red spruce trees 1 inch or more d. b. h. on plots with girdled trees and on control plot, in 1905 and at 5-year intervals thereafter.

girdled trees rose rapidly. In 1930, 30.9 percent on the plot moderately girdled and 47.0 percent on the plot heavily girdled was of merchantable size. By 1935 nearly half the volume on the plot moderately girdled and two-thirds the volume on the plot heavily girdled was of pulpwood size. This is equivalent to 4.9 cords and 11.4 cords, respectively, per acre. With 194 and 246 trees on plots 1 and 2, respectively, about to enter the merchantable-size classes, a considerable increase in merchantable volume may be confidently expected by the time of the next 5-year remeasurement period (fig. 4).

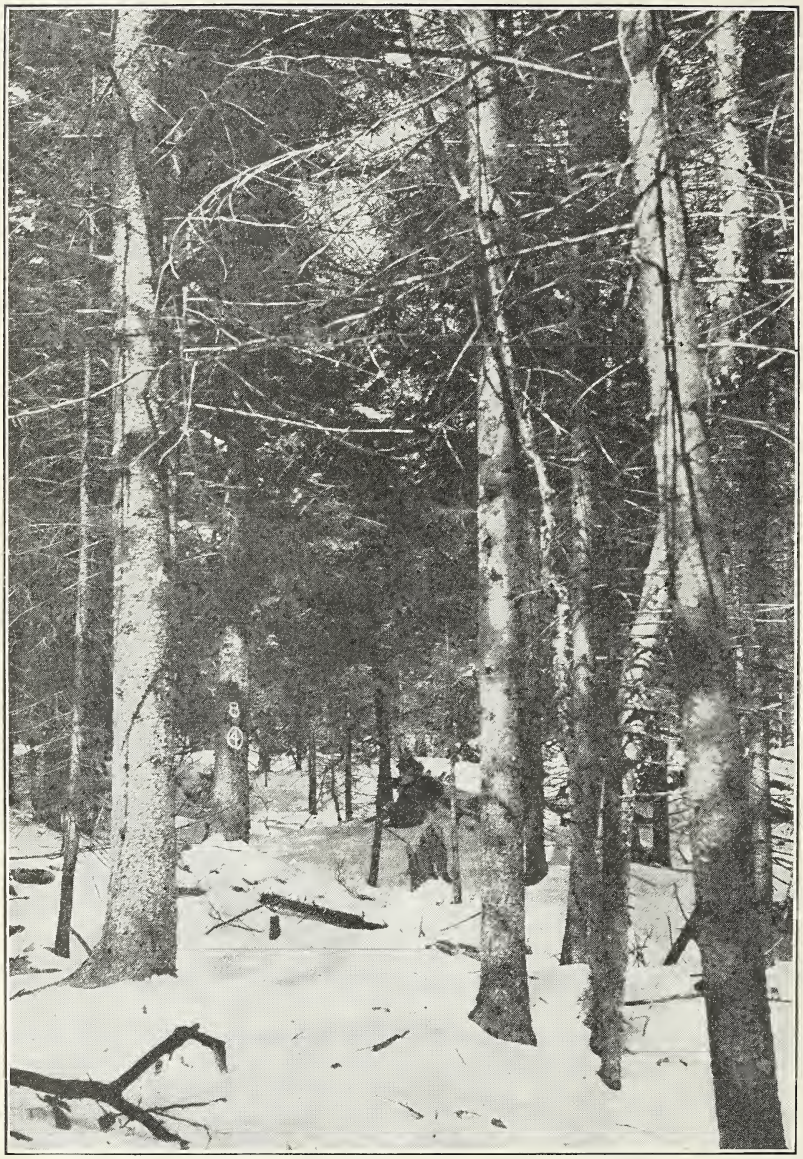

FIGURE 4.—Spruce on plot 2 now (1936) of merchantable size after being released by girdling hardwoods in 1905 and again in 1915.

TABLE 16.—*Periodic annual increment per acre of all red spruce trees 1 inch or more in breast-height diameter, 1905-35*

Plot no.	1905–10	1911–15	1916–20	1921–25	1926–30	1931–35	1905–35
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
1	10. 34	3. 26	17. 73	26. 94	65. 04	52. 41	29. 28
2	14. 22	19. 25	31. 15	42. 25	102. 94	93. 80	50. 60
3	6. 25	2. 66	6. 91	2. 41	1. 22	2. 32	3. 63

TABLE 17.—*Volume per acre of merchantable red spruce trees in 1905 and at 5-year intervals thereafter*

Plot no.	1905	1910	1915	1920	1925	1930	1935
	Cubic feet	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*	*Cubic feet*
1	2. 10	----------	----------	1. 90	18. 00	220. 20	465. 6
2	----------	----------	8. 00	21. 80	84. 30	534. 80	1, 084. 8
3	1. 70	2. 10	2. 30	4. 00	5. 70	23. 20	42. 6
	Cords	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*	*Cords*
1	0. 02	----------	----------	0. 02	0. 19	2. 32	4. 90
2	----------	----------	0. 08	. 23	. 89	5. 63	11. 42
3	. 02	0. 02	. 02	. 04	. 06	. 24	. 45

ON NET MERCHANTABLE YIELD

In order to determine the value of girdling carefully selected trees as a means of keeping a mixed hardwood-spruce stand in a healthy condition, the three plots were compared as to total sound basal area (table 7). Greatest basal area, 123.85 square feet per acre, was attained by the control plot in 1930, at which time plots 1 and 2 contained 95.90 and 88.88 square feet, respectively. The heart rot fungus *Fomes igniarius*, however, by 1935 had killed or rendered many of the aspen trees practically worthless, reducing the live basal area on the control plot to 103.95 square feet and the sound basal area to approximately 80 square feet per acre. Very little loss from defect occurred on plots 1 and 2, from which girdling had removed most of the defective trees and most of the aspen. Total sound basal area on plots 1 and 2 in the meantime had risen to 117.74 and 117.56 square feet per acre, respectively.

In a comparison as to net merchantable volume per acre in 1935 (table 18), the plot moderately girdled takes the lead, the plot heavily girdled is a close second, and the control plot stands last.

TABLE 18.—*Sound merchantable*[1] *volume of hardwoods and red spruce per acre, 1935*

Plot no.	Hardwoods [2]			Red spruce			Total	
	Cubic feet	*Cords*	*Percent* [3]	*Cubic feet*	*Cords*	*Percent* [3]	*Cubic feet*	*Cords*
1	744. 00	9. 3	61. 5	466. 00	4. 90	38. 5	1, 210. 00	14. 2
2	112. 00	1. 4	9. 4	1, 085. 00	11. 40	90. 6	1, 197. 00	12. 8
3	523. 00	6. 5	92. 4	43. 00	. 45	7. 6	566. 00	7. 0

[1] Minimum size, 10 inches diameter breast high for hardwoods, 5 inches for red spruce. Conversion factors used: Red spruce, 95 cubic feet equals 1 cord; hardwoods, 80 cubic feet equals 1 cord.
[2] Hardwoods expressed in cordwood unit to make possible direct comparison with red spruce volume.
[3] Percentage (of total) figures based on cubic-foot data.

In analyzing the factors responsible for the excellent conditions on the plots with girdled trees, the importance of the selective character of the girdling should not be overlooked. Gradual conversion of the stand

by relatively light initial girdling, followed some years later by heavier girdling doubtless minimizes the danger from wind, sun, frost, and insect injuries, which has been observed on areas where complete removal of hardwoods was accomplished in one operation. The beneficial effects of selective girdling in producing desirable mixed stands were especially apparent on plot 1.

FINANCIAL ASPECTS OF GIRDLING—COSTS AND RETURNS

Not only can girdling be relied upon to increase the rate of conifer pulpwood production in mixed spruce-hardwood forests of the Northeast, but it can be undertaken in this region with assurance of profit. This fact is established by balancing girdling costs against the value of the present and prospective conifer pulpwood yields.

In 1935, although relatively large volumes of spruce had been produced on the plots with girdled trees, spruce crop values were still low, particularly on the plot moderately girdled where only a relatively small proportion of the volume was of pulpwood size (tables 15 and 17). With conifer pulpwood rated at $2.50 per cord, the conifer pulpwood values per acre on the heavily girdled plot 2 and moderately girdled plot 1 totaled $28.55 and $12.25, respectively, while that on the control plot totaled only $1.12. Total girdling costs were estimated at $2.60 per acre for plot 2 and $2 per acre for plot 1. In the region in which the experimental plots lie, sound hardwoods of good quality find a ready market and command stumpage values equal to and often higher than spruce. If a value is assigned to hardwood stumpage, this increases the crop values on plot 1 more than on plot 2. If hardwoods are also rated at $2.50 per cord, the crop values of the hardwoods and spruce combined total $35.50 per acre on plot 1, $32 per acre on plot 2, and $17.50 per acre on plot 3.

This experiment has been in progress for a sufficient length of time and has yielded sufficiently definite indications to justify projecting the probable yields of conifer pulpwood on the plots to the year 1945, at which time, in the normal course, the greater part of the spruce on the plots with girdled trees will have reached pulpwood size. On the basis of the conservative estimate that growth will average 50 cubic feet per acre per year on plot 1 and 75 cubic feet per acre per year on plot 2 (these rates are less than the current rates on the two plots), it may be expected that in 1945 the volume of conifer pulpwood per acre will total 1,474 cubic feet on plot 1 and 2,357 cubic feet on plot 2. If the converting factor of 95 is applied to these cubic-foot volumes, they become 15.5 cords and 24.8 cords, respectively. At the present growing rate on the control plot, it is questionable whether by 1945 this plot will yield as much as 2 cords of spruce per acre. The prospective spruce volume gain attributable solely to the effects of girdling, therefore, amounts to approximately 13 cords on the plot moderately girdled and nearly 23 cords on the plot heavily girdled, the corresponding values amounting to $32.50 and $57.50, respectively.

Normally two courses are open to the operator who does not have sufficient acreage to assure future conifer pulpwood supplies for his mill: To buy more pulpwood land, or to increase the yield on his present holdings through forest management. According to the results of this experiment, the latter course is the more economical. A conservative interpretation of prospective pulpwood yields on the experimental

plots indicates that in areas where conifer pulpwood species have not been liberated at least 3 acres would be required to produce cordage equivalent to the yield per acre on the moderately girdled areas, and at least 5 acres to equal the yield per acre on the heavily girdled areas. Even at the low price of $2 per acre, purchase of 3 to 5 acres would represent an investment of $6 to $10, whereas the girdling investments required to attain corresponding conifer pulpwood yields would amount only to $2 and $2.60, respectively. Another advantage in girdling as compared with purchase of additional land is that a given operating capacity can be maintained on a smaller acreage with a considerable saving in taxes and in fire protection and other administrative costs. Even the operator possessing adequate acreage to assure his mill of continuous conifer pulpwood supplies may well consider the advantages which accrue from girdling to increase growth and yield on the most productive and accessible portions of his holdings.

SUMMARY AND CONCLUSIONS

Girdling of overtopping hardwoods has substantially increased spruce production on plots established by the Forest Service in 1905 at Corbin Park, N. H. At the beginning of the experiment the stand was composed of an almost pure hardwood overstory, the basal area of which averaged a little more than 100 square feet per acre, and a spruce understory containing few trees more than 2 inches in diameter. Three half-acre plots were established, the stands on which varied but slightly as to composition, age, total basal area, density, thrift, and reproduction. A relatively light girdling operation was carried out in 1905 and a more severe one in 1915, removing 71.4 percent of the hardwood trees on plot 1 and 90.3 percent of those on plot 2. Plot 3 was left undisturbed as a control. Measurements at 5-year intervals following the first girdling showed that the pulpwood species grew much more rapidly on the girdled plots than on the control plot in height, diameter, basal area, and volume. Stand composition on plot 1 improved through an increase not only in the proportion of conifer pulpwood species but in the proportion of better hardwood species.

In 1935 the stand of spruce on the plot heavily girdled amounted to 1,607 cubic feet per acre and that on the plot moderately girdled to 974 cubic feet per acre, in contrast with 172 cubic feet per acre on the untreated plot.

Plot 1, on which only the slow-growing and defective hardwoods and those of least desirable species were girdled, now supports the greatest total volume of merchantable wood of both conifer and hardwood species. In 1935 this plot had 1,210 cubic feet of merchantable spruce and hardwoods; plot 2, on which nearly all the hardwoods were girdled, had 1,197 cubic feet; and the control plot, on which heavy losses occurred during the experimental period as a result of decay, had only 566 cubic feet. Softwoods composed 38.5 percent and 8 percent, respectively, of the net merchantable stands of all species on plots 1 and 3, and 91 percent of that on plot 2. Because of the heavy stand of spruce just below merchantable size on the girdled plots, a much larger increase in merchantable volume may be expected on these plots in the next few years than on the check plot.

The experiment has shown that in the mixed spruce-hardwood type of the Northeast, girdling to release spruce is profitable from a financial standpoint. With approximately one-third of the spruce volume on

plot 2 and more than half of that on plot 1 still below merchantable size, the full benefits of the treatment will not be realized for some time. It is estimated that by 1945, when the bulk of the spruce has reached merchantable size, the net gain in conifer pulpwood volume attributable solely to the effects of girdling will amount to 23 cords per acre, worth $57.50, on plot 2, and to 13 cords valued at $32.50 on plot 1. The costs of heavy and moderate girdling are estimated at only $2.60 and $2, respectively, per acre.

Analysis of the data leads to the following conclusions:

1. Girdling has a definite place in the management of mixed spruce-hardwood forests of the Northeast.

2. Red spruce stands liberated by girdling produce conifer pulpwood several times as rapidly as comparable stands that are not liberated.

3. Selective or "improvement" girdling is effective in improving mixed spruce-hardwood stands and enhancing their value, particularly in localities where hardwoods have a potential market value. Selective girdling not only increases materially the growth rate of released conifers and hardwoods but has the effect of concentrating the growth of the stand on sound merchantable trees.

4. Wherever a satisfactory softwood understory is present, girdling of hardwoods will convert a mixed spruce-hardwood stand into a stand entirely of conifers.

5. Although complete girdling of hardwoods results in greater yields of conifer pulpwood than partial girdling, selective girdling has silvicultural advantages that make it preferable for the greater part of the area now occupied by mixed spruce-hardwood stands.

6. A series of two or three girdling operations, properly timed, has advantages over a single heavy girdling, because less danger of injury by wind, sun, and frost is involved.

7. Even in cases in which the conifer pulpwood crop cannot be harvested until 40 or 50 years after the girdling, satisfactory returns can be realized on the investment in girdling.

8. It appears that pulpwood operators can increase their future conifer pulpwood supplies more cheaply by increasing yields through girdling than by purchasing additional pulpwood lands.

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